Hard X-ray Microscopy Experiments at Beam Line 7.3.3

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INTRODUCTION

An important advantage of an imaging microscope is the ability to image many resolution elements at the same time. This parallel 'processing' capability is not only important for many interesting applications, but makes the best use of the incoherent light source, such as a bending magnet source of synchrotron radiation. Imaging microscopes working in the soft x-ray spectral region (E<1 keV) have been developed by many groups using synchrotron as well as laboratory x-ray sources[1-3]. Spatial resolution of about 30 nm has been demonstrated and is still improving. Up to now, however, there are no similar dedicated imaging microscopes working in the multi-keV x-ray spectral region using a bending magnet source. We have initiated a program of developing an imaging microscope, so far using 3-10 keV x-rays, from a bending magnet source. Our goal is to develop a dedicated imaging microscope and tomography facility at the Advanced Light Source (ALS) with a spatial resolution better than 100 nm. Both phase contrast and absorption contrast will be utilized.

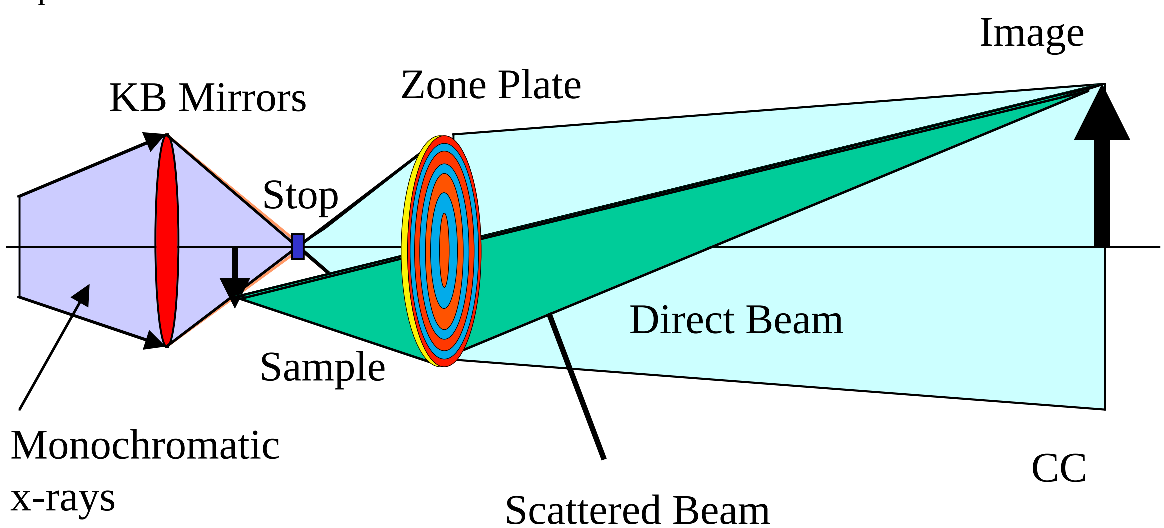

FIGURE 1. Schematic of the ALS microscope, showing operation in a dark-field mode. For bright-field the stop is removed, for phase contrast it is replaced by a phase shifter.

THE ALS MICROSCOPE

The schematic of an imaging microscope is shown in Fig. 1. At this point, we have experimented with the dark-field and bright-field mode. The dark-field mode is essentially a special form of the phase contrast in which the image contrast is proportional to the difference of scattering strength between two neighboring resolution elements, which is proportional to the square of the atomic scattering factor. Because of its low background, the dark field mode may be a preferred imaging technique for some special class of objects.

Our experiments have been conducted on the 7.3.3 beam line with typical energy resolving power about 1500, which ensures that the chromatic aberration of the zone plate is smaller than its intrinsic resolution. The zone plate determines the ultimate spatial resolution of this microscope assuming that the detector has adequate resolution. The zone plate was developed in a long-term collaboration of Argonne National Laboratory, University of Wisconsin at Madison, and Istituto di Electronica dello Stato Solid, Italy[5] [6]. Its key parameters are given in table 1.

TABLE 1. Key Zone Plate Parameters

Parameter	**Value**
Diameter	145 μm
Outer most zone width	103 nm
Au thickness	900 nm
Focal length at 8 keV	10 cm
Zone profile	Square-wave (binary)

The theoretical spatial resolution of the phase zone plate is about 120 nm and an experimental resolution very close to this value was achieved. The magnified image of an object is recorded by a detector system consisting of a scintillation screen, a 20X microscope objective, and a CCD detector of 24-μm pixel size. The x-ray and optical magnification were 21 and 11 respectively and the combined total magnification is therefore 294. Each pixel of the CCD detector, therefore, represents a feature size of 103 nm at the object plane.

EXPERIMENTAL RESULTS

Imaging of many objects ranging from biological to materials objects has been made using either absorption or dark-field phase contrast, depending on the type of contrast of the particular object. High quality images of objects ranging from lichen, bone joints, metal grid, human hair, a shark tooth, and semiconductor integrated circuits have been obtained.

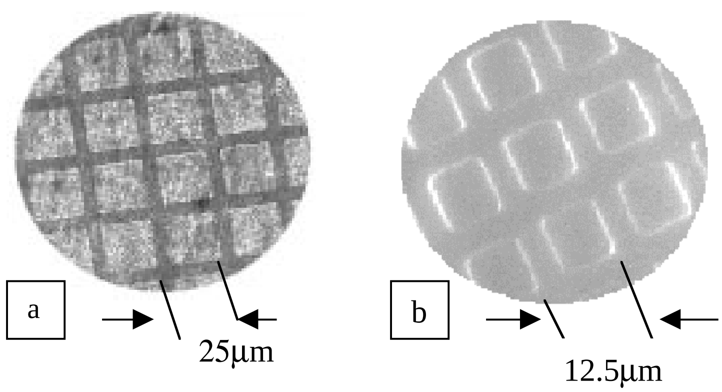

FIGURE 2. (a) Bright-field field image of a Cu 1000mesh/inch grid, and (b) dark-field image of a Cu 2000mesh/inch grid.

Fig. 2 shows images of Cu mesh grids obtained in bright-field (a) and dark-field mode (b). While the bright-field image (Fig. 2a) does represent a true image of the grid as image contrast is formed by the absorption of the 1000 mesh/inch Cu gird, the dark-field image only shows the boundary of the bars of the 2000 mesh/inch Cu grid. There is little difference in the image of the open area of the mesh grid and the centers of bars. Essentially, it may be considered as a derivative image of a regular phase or absorption image.

Fig. 3 shows the images of part of an integrated circuit chip supplied by Dr. Neogi of Intel Corp and in collaboration with Dr. Levin of NIST. The chip is made using the recent Cu technology for integrated devices. It consists of Cu interconnects at two layers connected by vias.

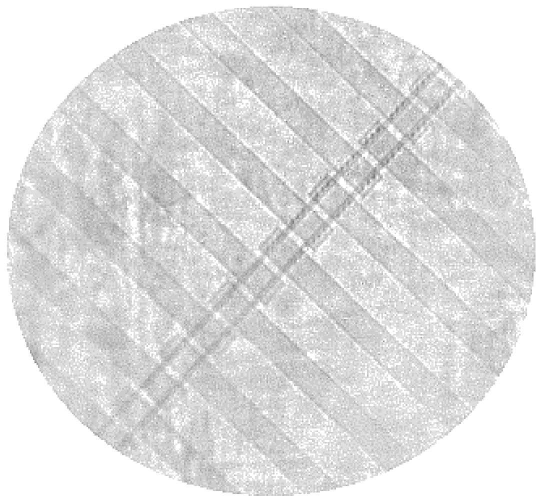

FIGURE 3. X-ray image of an integrated circuit showing vias connecting Cu wires in two different layers. The vias are the small dots at the intersection between the thin and wide Cu wires.

The figure shows clearly the image of the buried vias whose dimension is about 0.4 µm. Preliminary analysis indicates that the spatial resolution of the x-ray image is about 120 nm.

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